Chapter 4
Airfoil Theories and Their Applications

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ABSTRACT

One of the most important design impacts in aircraft is an airfoil. This airfoil is also considered the cross-section of the wing, so the flow characteristics of air depend on the airfoil's shape. There are some airfoil theories we can consider for the design consideration while designing the wing. The airfoil theories describe the nature of fluid flow over the wing based on the angle of attack for variable speed conditions. This chapter deals with airfoil terminology and the theories of airfoil like the methodology of conformal transformation, Cauchy-Riemann relations, complex potential, Kutta-Joukowski, thin airfoil theory, and their applications. The theories mentioned above explain transformation and its applications, Kutta condition, Kelvin's circulation theorem, starting vortex creation of airfoil for variable speed considered for aircraft, and the advantages of the optimization.

INTRODUCTION

Airfoil is the basic geometrical constraint to design a wing or blades in aerodynamic applications. The airfoil nomenclature is shown in figure 1 and the airfoil has a leading edge and trailing edge which is the initial and end portion of the airfoil. The shape of the airfoil is defined based on the airfoil theories and conditions to satisfy the aerodynamic performance characteristic and the nature of the aircraft is considered. The essential characteristics like the angle of attack are one of the important constraints which influence the aerodynamic performance of the aircraft. The angle of attack depends on the chord of the wing (Gudmundsson, 2013). The wing chord is the connecting line between the leading edge and the trailing edge of the airfoil. Since the start of the flight, a great variety of unique airfoils have been developed. These have a variety of features, some of which are excellent and others which are less so.

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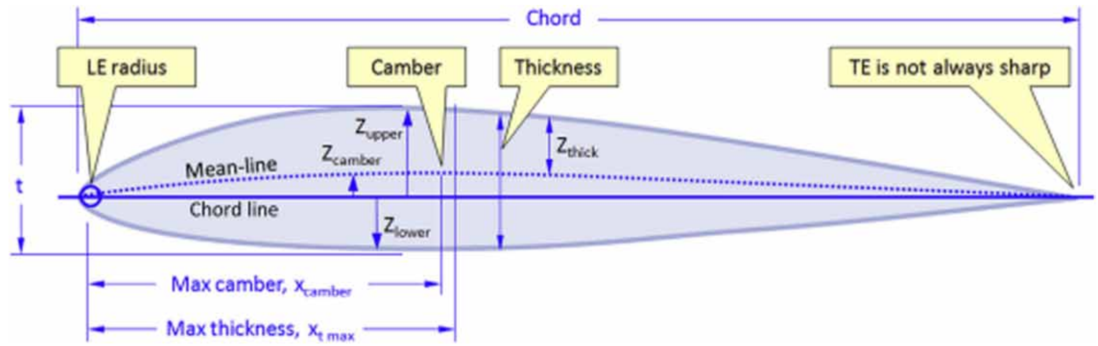
Figure 1. Airfoil nomenclature of a conventional aircraft
Source:(Snorri Gudmundsson, Chapter 8 - The Anatomy of the Airfoil)



Typically, airfoils are designed using direct analysis and inverse design. Every design is based on the properties of airfoil (Houghton and Carpenter, 2003; Arfken et al., 2013). The properties of the airfoil were also similar to the aerodynamic characteristic of a body since the airfoil is used to design the wing. So the properties like lift coefficient (CL), Angle of attack, Minimum Drag Coefficient (Cdmin), Lift Curve Slope (CLα), and The pressure coefficient (CP) are very important parameters also influencing the performance of the wing. Based on the properties and the shape the airfoil is designed in a variety of configurations. The design of airflow over a wing is complex often for various geometrical aspects like an asymmetrical, asymmetrical wing. Conformal mapping is a critical technique that is used to solve complex airfoil flow conditions with the fewest geometric constraints. This method is used to represent an airfoil by comparing the solution for a sphere to that for an airfoil using the Joukowski transformation. Through the use of an inviscid, incompressible viscous fluid model, the flow around a cylinder was calculated by superimposing elementary potential flows. The modified flow equations and basic theories of meteorology were used to calculate lift as a function of the angle of attack for each airfoil. Mathematical equations were used by the NACA to develop its early airfoil series, which included the 4-digit, 5-digit, and modified 4-/5-digit designs. These equations define the camber (curvature) and thickness variation along the length of the mean-line (geometric centerline) of the airfoil section. For example, the shape of the 6-Series was developed using theoretical rather than geometrical methods, which results in a more intricate appearance. Before the National Advisory Committee for Aeronautics (NACA) produced this series, the shape of an airfoil was determined by historical experience with known shapes and experimental alterations (Catwell, 2014).

Conformal Mapping

A conformal map is a way to transform a complex-valued function from one coordinate system to another. Applying a transformation function to the original complex function accomplishes this objective. Consider the complex plane Z in figure 2 as an example. The complex function Z, $Z=x+iy$ is used to define coordinates in this plane. The x-direction streamlines are given by and the equipotential curves are given by $\varphi = x$ in this illustration of a basic uniform fluid flow.

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